Journal of Testing and Evaluation

doi:10.1520/JTE20180022 / Vol. 47 / No. 3 / 2019 / available online at www.astm.org

Wynand J. van der Merwe Steyn[1]

Optimization of Gravel Road Blading

Reference

W. J. v.d.M. Steyn, "Optimization of Gravel Road Blading," *Journal of Testing and Evaluation*, 47, no. 3 (May/June 2019): 2118–2126, https://doi.org/10.1520/JTE20180022

Manuscript received January 12, 2018; accepted for publication April 17, 2018; published online September 10, 2018.

[1] Department of Civil Engineering, University of Pretoria, Lynnwood Rd., Hatfield, Pretoria 0083, South Africa (Corresponding author), e-mail: wynand.steyn@up.ac.za, https://orcid.org/0000-0001-5893-3733

ABSTRACT

Blading maintenance of gravel roads is important to ensure that the functional performance of the road is optimal and that vehicle operating costs are minimized. In order to optimize the blading cycles, a system is required to monitor the functional performance of the road and inform the blading need. This system should preferably be low-cost and simple to operate, as the budgets available for such maintenance is typically low, and the condition needs to be monitored frequently because of the relatively quick deterioration in the functional performance of these roads through factors such as corrugation development. A method is described where the monitoring of the functional performance of gravel roads can be done at a regular frequency at no additional cost to the road owner. The effect of blading maintenance decisions taken based on the use of this system on a small gravel road network is illustrated. The optimization leads to fewer blading requirements, as only the sections where functional performance was inadequate were maintained, and in the long term, the condition of the road improved through regular appropriate blading.

Keywords

gravel road blading, functional performance, optimization

Introduction

Roads (similar to all infrastructure) deteriorate with time and use and are thus in constant need of maintenance to ensure optimal functional condition [1] and to support the social and economic requirements of the community [2]. Blading maintenance of gravel roads is one of the engineering options to ensure that the functional performance of the road is optimal and that vehicle operating costs are minimized [3]. In order to optimize the blading cycles, a system is required to monitor the functional performance of the road and inform the blading need. This system should preferably be low-cost and simple to operate, as the budgets available for such maintenance are typically low, and the condition needs to be monitored frequently because of the relatively quick deterioration in the functional performance of these roads through factors such as corrugation development.

A method is described in which the monitoring of the functional performance of gravel roads is conducted at a regular frequency and no additional cost to the road owner, using an innovative Response Type Road Roughness Measurement System (RTRRMS). The effect of the blading maintenance decisions made based on the use of this system on a small gravel road network is illustrated. The optimization leads to fewer blading requirements, as only the sections where functional performance is inadequate are maintained, and in the long term, the condition of the road is improved through regular appropriate blading.

Background to Road Maintenance and Roughness

ROAD MAINTENANCE

For the effective maintenance of gravel roads, it is important to have access to a Pavement Management System that can assist in supporting a long-term stable budget, ensuring a sustainable road network, and supporting the development of maintenance strategies to achieve this [4].

Road maintenance is the process in which the condition of a road needs to be monitored at regular intervals, and these condition data are used to make decisions regarding the required maintenance. The condition monitoring can include aspects such as the visual condition, functional condition, and structural condition of the road [5,6]. One of the functional condition aspects is the riding quality of the road. The level of riding quality (or road roughness) is directly linked to road safety, user perception, and road user costs on the road [7,8].

In order to manage the maintenance of roads, minimum standards are set for the condition level of the various condition parameters on a road. In South Africa, the current guideline for riding quality of gravel roads indicates a minimum riding quality of 7 m/km on such roads [9].

RIDING QUALITY

The riding quality of a road is indicative of the condition of the road [10] and can be monitored using two main types of monitoring [11], which are Response Type Road Roughness Measurements (RTRRM) and Profilometric Type (PT) measurements. Each of these approaches has distinct advantages and limitations, with RTRRMS using the calibrated response of a vehicle traveling over the road to indicate the roughness level while profilometric methods use a laser-based measurement of the profile of the road surface that is mathematically analyzed using the Quarter-Car model to calculate the roughness [12]. Both systems provide a roughness level in terms of the International Roughness Index (IRI), which provides a mathematical indication of the physical response of a standardized vehicle to the road profile. The typical IRI scale runs from 0 m/km (perfect surface) to 20 m/km (impassable) [8]. Studies such as Refs. [13,14] have shown that the RTRRMS technique is highly related to the Class I PT measurements, if done accurately.

In general, the profilometric approach is more modern and sophisticated and provides more consistent data. However, the approach requires significantly more expensive equipment and in-depth understanding and monitoring of the measured data, and the system cannot typically be used on unpaved or gravel roads because of the dust generated during traveling on the road. The RTRRMS requires a calibrated vehicle that travels at a constant speed with a constant mass to ensure that the response of the vehicle to the road condition is not affected by external factors [11]. Newer telematics-based RTRRMS uses algorithms that incorporate a range of speeds and vehicle types in the determination of the riding quality [15].

Roughness data are often used for dividing a road into statistically homogeneous units that are used for establishing preferences for maintenance and rehabilitation [16].

Experiment and Methodology

In this article, a process is described that was developed for the management of gravel road conditions for a major agricultural business in the northern part of South Africa [17]. The process required regular monitoring of the road condition, as the deterioration of the road riding quality has a direct influence on the quality of the agricultural produce transported over the road system [18,19]. A separate methodology for the quantification of the inter-fruit stresses developed during the transportation of fruit (tomatoes specifically) is used in conjunction with this methodology to quantify the levels of distress caused by road conditions on transported fruit [20].

The measurement system consisted of measuring the vertical accelerations on a Light Delivery Vehicle (LDV) on specific gravel routes before and after grading the route. Data were collected at 15 intervals over a period of 7 months. During this period, the road was graded three times. The data analysis focuses on the comparison between the vertical acceleration data as measured using the LDV. All measurements were conducted traveling in the same direction on the route. Vehicle speed was kept constant by monitoring global positioning system (GPS)-based speed and keeping the speed to 40 ± 5 km/h during any run.

This methodology was based on experimentation over a period of approximately a year, in which various different types of measurement systems were evaluated with the aim of obtaining a low-cost simple and accurate system. The methodology also had to be simple enough to be operated by the normal road users during their daily tasks, without excessive additional workload added to their procedures.

An accelerometer was rigidly installed on the tow-bar of the LDV (see **Fig. 1**), and the route was monitored using a calibrated GPS. The accelerometer data were collected at a frequency of 50 Hz, and the focus was on the vertical accelerations. The collected acceleration data were analyzed through a set of algorithms to determine the Coefficient of Variation (CoV) of the vertical acceleration data that was then converted to Half-car Roughness Index (HRI—calculated by applying the IRI algorithm to the average of the wheel path profiles) values, using a set of calibration equations that were developed for the specific vehicle and vehicle conditions. The CoV values were calculated over 10 intervals, using the 50 Hz data. Riding quality data were averaged over 250 m sections, as these are deemed the shortest practical section lengths for grader-based road maintenance. The final data consisted of the locations and calculated riding quality over the length of the road at the selected intervals.

FIG. 1

Accelerometer rigidly attached to LDV tow bar.

Data Analysis

In the data analysis, attention was focused on the repeatability between measurement runs (vehicle location) and the measured acceleration response of the vehicles.

VEHICLE LOCATION

Vehicles traveling on a gravel route typically wander (i.e., travel on different wheel paths across the width of the road) across the road, depending on the location of the smoothest ride on the road. A driver will typically try to select a route on the gravel road that prevents interaction with anomalies such as protruding rocks and corrugations. This wandering action may affect the observed riding quality data significantly if the driver is managing to maneuver in such a way as to miss vital riding quality anomalies on the road. In order to address this possible flaw in the procedure, guidance was provided to the drivers to firstly understand the objective of the measurements (to obtain an accurate indication of the riding quality of the road) and then to follow a relatively straight route over the road without being influenced by alternative alignments over the width of the road. The actual routes followed by the LDV were analyzed by comparing the GPS-based location data over the length of the route. The typical accuracy of the GPS used was ±4 m.

An analysis of the scatter in wheel tracks followed for the various runs on the road (see **Fig. 2**) indicates relative close spacing between the runs, with analysis of these wander data indicating that wander ranged between 1.9 m and 6.7 m with an average of 4.0 m. If it is assumed that the average is due to GPS location issues and not physical wandering of the LDV, then the width of the wander ranges between an average of 0.0 m and 2.4 m, and thus, the tires can be running on a totally different wheel track for different measurements if care is not taken in the measurements. The use of an experienced driver to conduct the measurements indicated that the wander could be brought down to less than 0.5 m between runs.

RIDING QUALITY—ACCELERATION RESPONSE

The collected data show the location of the vehicle along the length of the road with the measured vertical accelerations and CoV of accelerations (see **Fig. 3**). In this data,

FIG. 2

Indication of wheel tracks followed for different runs during road maintenance measurements.

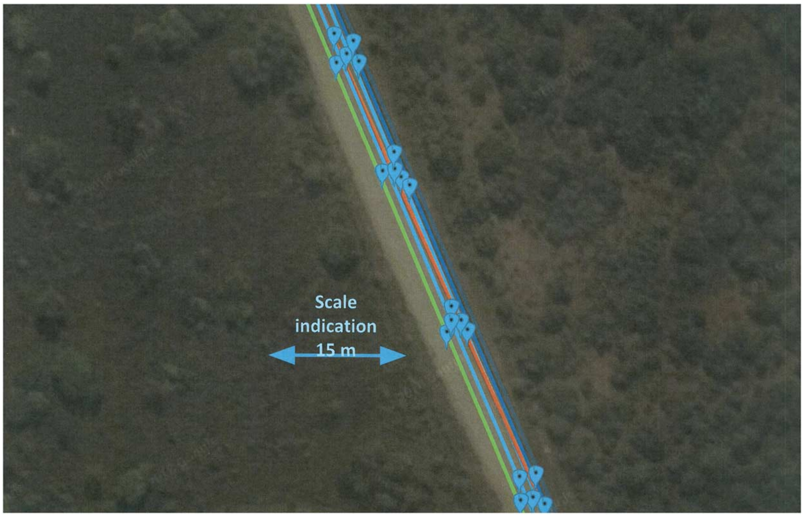
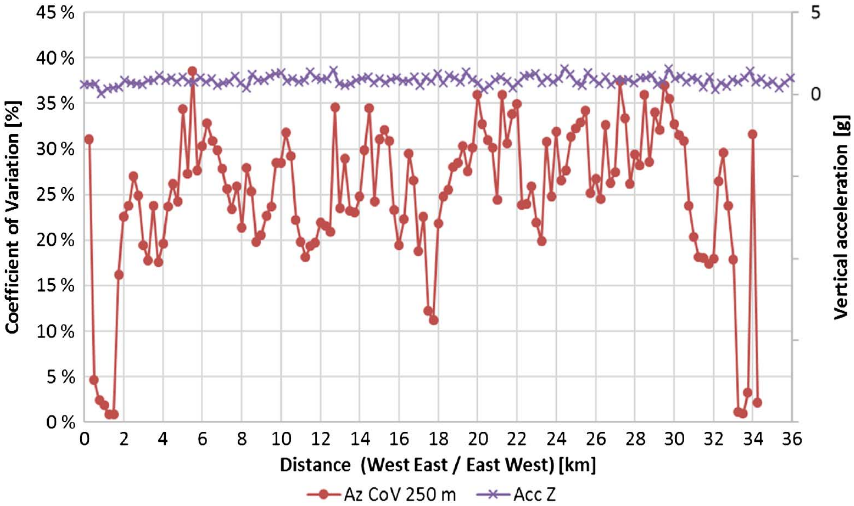


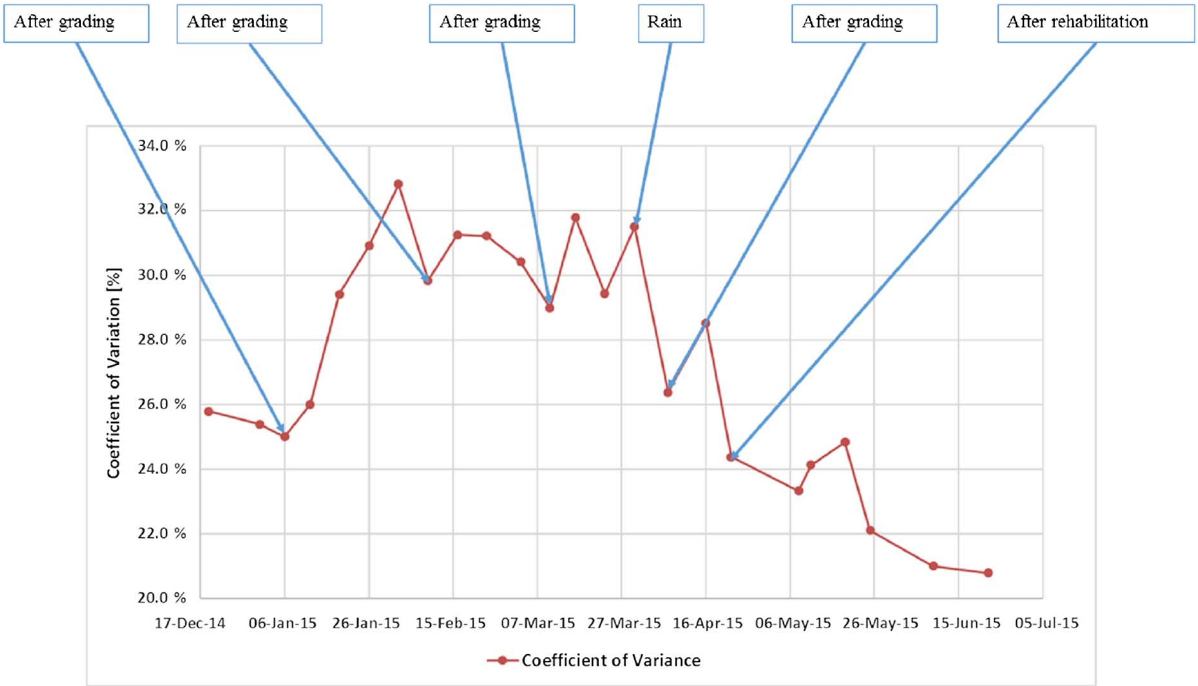
FIG. 3

Typical vertical acceleration data.



the different sections on the gravel road, based on changes in the vehicle response (and thus riding quality), are visible. Further analysis of all the vertical accelerations measured on the route at the intervals indicated generates the data in Fig. 4. It can be seen from the data that the CoV of vertical acceleration (indicative of HRI) increases after grading the road (with the use of the road by a range of vehicles) and then improves again after the next grading. In one instance, a heavy rainfall caused relatively quick deterioration of the riding quality due to the use of the road under very wet conditions. After ultimate rehabilitation of the road (which included major improvement in materials and construction options), the road condition remained good for a number of runs. Some of the variation in the data is attributable to vehicle wandering.

FIG. 4 CoV affected by time and grading operations.



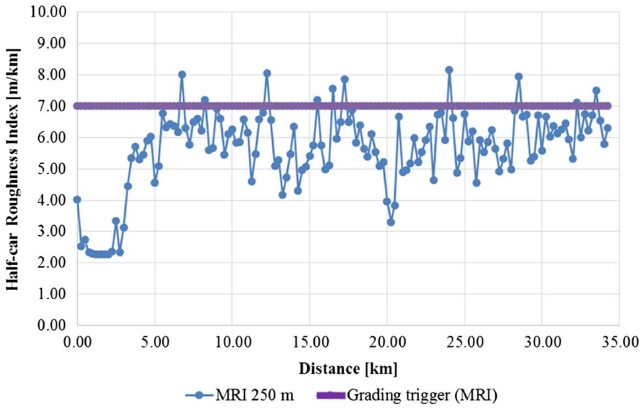
If needed, the response of the LDV can be calibrated using a Class I riding quality measured road section to provide an indication of the riding quality in terms of HRI. However, this is not always needed (specifically when no such Class I sections are available in the vicinity of the road network that needs to be monitored—which is often the case with rural gravel road networks). If needed, a standard calibration effort will require the Class I measurement of a section of road (preferably a paved section) that contains similar riding quality ranges than what is expected to be measured using the LDV RTRRMS. A number of runs over this road section at a constant speed and load will be completed using the instrumented LDV, and a calibration relationship is developed between the Class I and Class III data. This needs to be repeated if there are changes in the condition of the components of the LDV, as per the normal RTRRMS calibration procedure [11]. The use of a different vehicle for measurements will affect the values of the measurements but not the indication of relative riding quality. Such an alternative measurement vehicle should thus first be calibrated against the initial vehicle, or the Class I section, for direct comparisons to be made between the measurements from two different vehicles.

PRACTICAL APPLICATION

In order for the data in the road maintenance analysis to be of practical value, a management value needs to be defined that can be used to monitor the change in the condition of the route until a certain trigger value is reached, at which stage grading of the route is recommended. In this regard, the terminal riding quality value of 7 m/km [9] is used in the current application of the process for the road owner. As access to a Class I measured

FIG. 5

Typical grading maintenance report.



section was available in the area described in this article, such a correlation was done, and the RTRRMS data could thus be expressed as Class III HRI data. Regular measurements are conducted on the selected roads and a grading recommendation develops (see Fig. 5) where only the sections with riding quality values more than the trigger value of 7 m/km are recommended to be maintained.

The grading recommendation consists of a short report highlighting the sections of the road that have higher-than-terminal riding quality and are thus in need of grading. The application of this process has saved the road owner between 40 and 60 percent of grading costs, as only sections that are worse than the minimum riding quality are actually graded.

A current process is focusing on the translation of the riding quality changes to the expected damage to transported tomatoes based on a set of relationships developed between the riding quality of the road and the effect on the shelf-life of the tomatoes [20]. These relationships are dependent on the type of tomato, the number of layers of tomatoes in a container on the vehicle, and the ripeness levels of the tomatoes. This provides a direct management tool to the agricultural company in terms that are applicable to the specific agricultural environment.

An improvement in the process described in this article is being developed by Wessels [14] in which telematic units that are incorporated into the instrumentation of the vehicles are used to monitor the vehicles' responses to road condition. These data are then automatically collected and routed to a central data warehouse, where they are analyzed and automatically fed back into the pavement management system of the road owner for appropriate maintenance follow-up.

In a current follow-up study, the economic benefits of the proposed methodology is being evaluated. This requires input data originating from the vehicle fleet (volume and type of vehicles using the road, fuel consumption, and damage to vehicle due to road condition), road materials (affecting the deterioration rates of the road and change in riding quality), climate (affecting the deterioration rate of the road), general operational conditions of the vehicle fleet, and maintenance costs (grader operating costs). The outcome of that study will be presented in a separate article. Initial indications with one road owner indicated savings between 40 % and 60 % in direct maintenance costs.

Conclusions

Based on the data collected in the project and discussed in this article, the following conclusions are drawn:

- It is possible to measure the riding quality and change in riding quality of a gravel road consistently using a calibrated RTRRMS;
- The measured riding quality data can be used to monitor the effect of maintenance actions on the gravel road through changes/improvements in the measured riding quality; and
- The measured riding quality data can be converted to a management tool for the road user that provides a direct understanding of the effect of the road condition on the economic operations on the road, as well as a road maintenance trigger system.

ACKNOWLEDGMENTS

The support of the Tomato Producers Organization, ZZ2, and the University of Pretoria (financial support) are acknowledged. This work is partly based on the research supported in part by the National Research Foundation of South Africa. The Grant Holder acknowledges that opinions, findings, and conclusions or recommendations expressed in any publication generated by NRF-supported research are that of the authors, and that the NRF accepts no liability whatsoever in this regard.

References

[1] Jordaan, G., *Optimisation of Flexible Road Pavement Rehabilitation Investigations and Design*, University of Pretoria, Pretoria, South Africa, 2015, 374p.

[2] Han, D. and Do, M., "Evaluation of Socio-Environmental Effects Considering Road Service Levels for Transportation Asset Management," *J. Test. Eval.*, Vol. 44, No. 1, 2016, pp. 679–691, https://doi.org/10.1520/JTE20140484

[3] Federal Highway Administration, "Gravel Roads Construction & Maintenance Guide," *U.S. Department of Transportation*, Washington, DC, 2015, 141p.

[4] Martin, T. and Kadar, P., "Impact of Various Maintenance Strategies on Unsealed Road Deterioration to Achieve an Acceptable Maintenance Budget & Road Performance," presented at the *Ninth International Conference on Managing Pavement Assets*, Washington, DC, May 18–21, 2015, AASHTO, Washington, DC—unpublished.

[5] Southern African Development Community, *SADC Guideline on Low-Volume Sealed Roads*, Southern African Development Community, Gaborone, Botswana, 2003, 288p.

[6] South African National Roads Agency SOC Ltd., *South African Pavement Engineering Manual*, 2nd ed., South African National Roads Agency SOC Ltd., Pretoria, South Africa, 2014, 1286p.

[7] Heggie, I. G., *Managing and Financing of Roads: An Agenda for Reform*, World Bank, Washington, DC, 1995, 158p.

[8] Sayers, M. W. and Karamihas, S. M., *The Little Book of Profiling: Basic Information About Measuring and Interpreting Road Profiles*, University of Michigan, Ann Arbor, MI, 1998, 102p.

[9] Henderson, M. and Van Zyl, G., "Management of Unpaved Roads: Developing a Strategy and Refining Models," presented at the *36th Southern African Transport Conference*, Pretoria, South Africa, July 10–13, 2017, University of Pretoria, Pretoria, South Africa, pp. 61–78.

[10] Sayers, M. W. and Karamihas, S. M., *Interpretation of Road Roughness Profile Data*, University of Michigan Transportation Research Institute, Ann Arbor, MI, 1996, 180p.

[11] Jooste, F. J., "Guidelines for Network Level Measurement of Road Roughness: Version 1.1," *South African Committee of Transport Officials*, Pretoria, South Africa, 1997, 45p.
[12] Sayers, M. W., Gillespie, T. D., and Paterson, W. D. O., *Guidelines for Conducting and Calibrating Road Roughness Measurements*, World Bank, Washington, DC, 1986, 96p.
[13] Wessels, I. and Steyn, W. J. vdM., "Real-Time Monitoring of the Extended Road Network by Utilising Telematics Technology," presented at the *Fourth Chinese European Workshop on Functional Pavement Design*, Delft, the Netherlands, June 29–July 1, 2016, CRC Press, Leiden, the Netherlands, pp. 1645–1656.
[14] Sayers, M. W., Gillespie, T. D., and Queiroz, C. A. V., "The International Road Roughness Experiment: A Basis for Establishing a Standard Scale for Road Roughness Measurements," *Transportation Res. Rec.*, No. 1084, 1986, pp. 76–85.
[15] Wessels, I., "Vehicle Telematics and the Development of Road Condition Trends from Big Data," *M. Eng. dissertation*, University of Pretoria, Pretoria, South Africa, 2018.
[16] Divinsky, M., "Repeatability Analysis of Road Roughness Measurements," *J. Test. Eval.*, Vol. 28, No. 5, 2000, pp. 378–394, https://doi.org/10.1520/JTE12126J
[17] Steyn, W. J. vdM. and Coetzer, S., "ZZ2 Houtbosdorp Bakkie Grading Measurements," *University of Pretoria*, Pretoria, South Africa, 2015, pp. 378–394.
[18] Pretorius, C. J. and Steyn, W. J. vdM., "The Influence of Road Condition on the Shelf-Life of Tomatoes," presented at the *Fourth Chinese European Workshop on Functional Pavement Design*, Delft, the Netherlands, June 29-July 1, 2016.
[19] Pretorius, C. J., "The Influence of Road Condition on the Shelf Life of Tomatoes," *M. Eng. dissertation*, University of Pretoria, Pretoria, South Africa, 2017.
[20] Steyn, W. J. vdM., "A Novel Method for the Quantification of Interfacial Tomato Stresses During Transportation," *Res. Agr. Eng.*, Vol. 63, No. 3, 2017, pp. 128–135, https://doi.org/10.17221/64/2015-RAE